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INDUSTRIAL-HYGIENE ASPECTS OF UNDERGROUND OIL-SHALE MINING*

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IH Aspects of Underground Oil Shale Mining

INTRODUCTION

The United States contains vast deposits of oil shale. The high-grade deposits of the Green River Formation of Colorado, Utah, and Wyoming are estimated to contain some 95 billion m^3 (600 billion bbl) of recoverable shale oil.[1] At current rates of consumption, these resources alone could supply this country's liquid fuel needs for many decades. Despite this potential and substantial interest in producing oil from these deposits since the early 1900's, there are still no commercial shale oil facilities in the United States. Two commercial-scale facilities are under construction north of the town of Parachute, Colorado, and are expected to begin operation in the next several years. The facilities are being constructed by Union Oil Company of California and the Colony Oil Shale Project (a partnership of Exxon Corp. and Tosco, Inc.). Additional commercial facilities are in the planning and development stage. All or almost all of the near term development is expected to occur in Colorado and Utah with oil shales from the Green River Formation.

Oil shale must be heated (retorted) to some 500°C to break down the waxlike hydrocarbon known as kerogen to produce combustible gases and shale oil. Processes being developed to produce shale oil consist of 1) aboveground processing, in which oil shale is mined and transported to metal retorting vessels located on the ground surface, and 2) *in situ* retorting, in which the oil shale is fractured by explosives to create retorts in the ground. *In situ* retorts being developed include both true *in situ* retorts in which no mining occurs prior to creation of a retort, and modified *in situ* (MIS) retorts in which 20 to 40 per cent of the oil shale is mined prior to creation of a retort. Aboveground processing of oil shale is further developed, and the first commercial shale oil facilities will employ aboveground processing.

Process unit operations for shale oil production in aboveground facilities include mining (either underground or open pit), shale preparation and handling, retorting, disposal of retorted or "spent" shale, and retort product cleaning, upgrading, and storage. This paper discusses the industrial hygiene aspects of only the first of these operations, mining, and is limited to underground mining of oil shale. Mining in support of aboveground processing and in support of MIS retorting are discussed.

The majority of the information available on oil shale mining--whether related to the composition of oil shales, the techniques and equipment to be used, or potential health hazards--relates to oil shales from the Green River Formation. For this reason, this paper is necessarily directed towards the mining of Green River Formation oil shales.

Knowledge of potential health impacts to oil shale miners is limited because of the limited experience with oil shale mining in the U. S. Several short-term industrial hygiene air sampling studies have been conducted at experimental oil shale mines over the past ten years. These have included studies by or for the Bureau of Mines,[2,3] Los Alamos National Laboratory (Los Alamos),[4-6] the Mine Safety and Health Administration (MSHA),[7,8] and the National Institute for Occupational Safety and Health (NIOSH).[9] Air sampling studies have also been conducted by the Colony Development Operation, Occidental Oil Shale, Inc., and the Rio Blanco Oil Shale Company; however, results of the studies by private industry have not been reported.

Commercial-scale mining and processing of oil shale has occurred in the Estonian region of the U. S. S. R. for the past 35 years. An oil shale industry also existed in Scotland for close to 100 years. Although characteristics of the oil shales in these areas differ from those of the Green River Formation, experiences in these areas may suggest potential health concerns for a U. S. industry.

Mining equipment and techniques in oil shale mining are expected to be very similar to other types of mining already employed in the U. S. Potential health hazards in oil shale mining may be expected to be similar to mines using similar mining equipment and techniques. Certain types of industrial hygiene data from such mines may be useful in evaluating oil shale mining. Controls for these hazards may also be expected to be similar.

UNDERGROUND OIL SHALE MINING

Oil shale mining may be best characterized by its huge scale. The high-grade oil shales of the Green River Formation average some 115 L/tonne (28 gal/ton). Some 64,000 tonnes (70,000 short tons or st) of oil shale must be mined each day in order to produce 7,900 m^3/day (50,000 bbl/day) of shale oil in an aboveground retorting facility. All of the underground mines proposed for support of aboveground processing of oil shale will utilize room-and-pillar mining. Figure 1, from Reference 10, contains a diagram of the room-and-pillar mining concept for oil shale. The room-and-pillar technique has been tested in several experimental oil shale mines by the Bureau of Mines as well as by Union Oil Co. of California, Colony Development Operation, Mobil Oil Company, and Paraho Development Corp. Conventional mining techniques of drilling, blasting, loading and hauling, scaling, and roof bolting will be utilized in commercial oil shale mines.[10-14] Mining in support of MIS retorting will also involve the same mining techniques, but will not involve the room-and-pillar approach. A diagram of an MIS retorting operation in an experimental oil shale mine is shown in Fig. 2.

Rooms in commercial oil shale mines will be approximately 18 m (55-60 ft) wide, pillars will be approximately 18 m square, and the mine roof will be approximately 18 m high. The entire 18 m height will probably be achieved in two phases: 9 m will first be mined with drilling into the wall, and a second 9 m will be mined by drilling into the floor. Figure 3 is a photograph taken within an experimental oil shale mine which shows the scale of the rooms and pillars. A room-and-pillar mine of 60,000 tonne/day capacity (as proposed at the Colony project [10]) will be the largest such mine in the world. By comparison, the largest existing underground mine in the U. S. is reported to yield some 45,000 tonnes/day (50,000 st/day).[12]

Entry into mines located along the outcrop of the southern edge of the Piceance Basin (oil shales in Colorado are primarily in the Piceance Basin; those in Utah are in the Uinta Basin) will be by adits into the rich Mahogany zone from portal benches constructed on the edge of canyon cliffs. Figure 4 shows a haulage truck leaving an adit at an experimental oil shale mine. Underground mines in the center of the Piceance Basin will require vertical shafts for entry to the richer oil shale zones which may be covered by hundreds of meters or more of overburden. Figure 5 presents a photograph of a headframe for a hoist on a vertical shaft at an experimental oil shale mine in the center of the Piceance Basin. Entry into underground mines in the Uinta Basin will also be by shafts or inclines.

It is expected that all mining equipment in underground oil shale mines will be diesel powered. The drilling of horizontal blastholes into the wall will be conducted with rotary jumbos, as shown in Figs. 6 and 7. Blasting will generally be conducted with a prilled ammonium nitrate/fuel oil (ANFO) mixture. Loading or mucking will be conducted using front-end loaders of some 7.6 m^3 (10 yd^3) or larger capacity. Figure 8 shows a photograph of a mucking operation in an experimental oil shale mine. The oil shale will be hauled by trucks of some 45-70 tonne (50-80 st) or larger capacity. After mucking, the walls and ceiling are scaled (scraped with a pick on a mechanical arm) to remove any loose rock. Figure 9 shows a photograph of equipment used for scaling at an experimental oil shale mine. Holes are then drilled into the roof for installation of rock bolts to insure the integrity of the roof against rock falls.

Rotary blasthole drills will be used to drill vertical blastholes down into the lower bench. Blasting, mucking, and hauling will be the same as in the upper bench mining. It is anticipated that scaling will only be required up to the level of the previous floor. No additional roof bolting should be required in the mining of the lower bench.[10]

Primary and perhaps even secondary crushing of the oil shale may also be carried out underground in some oil shale mines.[14] The oil shale is hauled and dumped into a hopper which leads to a grizzly which screens out the oversize rocks. Mechanical rock breakers are used to break the oversize rocks into pieces that will go through the grizzly. After crushing, the material is carried from the mine on conveyor belts or hoisted up vertical shafts in self-dumping buckets or "skips."

POTENTIAL HEALTH HAZARDS IN UNDERGROUND OIL SHALE MINING

The mining of oil shale will result in a number of potential health hazards to workers. These include exposure to oil shale dusts, diesel exhaust from mining equipment, gases and vapors produced in blasting, gases released from mine water or the oil shale deposits, and exposure to noise, vibration, and heat generated by heavy mining equipment. Mining may take place under stressful environmental conditions of insufficient lighting as well as cold, dampness and high humidity.

The majority of these potential health hazards are not unique to oil shale mining, and most appear amenable to control by techniques used in other types of mining. Modified _in situ_ retorting may present unique occupational exposure problems, as discussed later in this paper. The hazards in oil shale mining have not been well characterized, so it is not possible to truly define the risks to miners at this time. Mining on the scale proposed for oil shale development has also not been conducted previously, and the equipment and techniques of control have not been demonstrated on such a scale.

Exposure to Dusts. Airborne dust is considered be the most important potential health hazard to underground oil shale miners.

Drilling of blastholes, blasting of the ore with explosives, mucking and haulage of the ore, scaling of the newly exposed surfaces, and crushing of the ore all generate airborne dust.

One may first evaluate the hazard potential of a dust by examining the chemical composition of the parent material. Oil shale is a rock in which the mineral portion is associated with a complex, high-molecular weight organic material. The mineral portion of oil shale from the Green River Formation is primarily a marlstone or mixture of calcium and magnesium carbonates with some quartz, silicates, and other minerals. The quartz content of Green River oil shale is reported to range from 10 to 20 per cent.[15] Trace elements of potential concern and their reported concentrations include: arsenic, 44.3 ppm; cadmium, 0.64 ppm; lead, 26.5 ppm; mercury, 0.089 ppm; and nickel, 27.5 ppm.[16] The organic portion of oil shale is principally a waxlike material known as kerogen which is of such high molecular weight that it is not extractable in common organic solvents such as benzene. A second organic component is bitumin, which is of somewhat lower molecular weight than kerogen and is extractable in organic solvents. Green River oil shale is reported to average some 85 per cent mineral matter, 11 per cent kerogen and 3 per cent bitumin.[17]

The presence of crystalline silica such as quartz in oil shale suggests the potential for fibrogenic lung disease. Results of inhalation toxicology studies at Los Alamos with raw and spent oil shales are discussed at this conference by L. M. Holland. No definitive correlation of pneumoconiosis with oil shale dust exposures has been found in U. S. oil shale workers, but medical surveys have been very limited.[15,18] The duration of exposures of those studied has also been short--usually less than 5 years--and many of the oil shale workers have had equal or longer duration of work in hard rock mines.

Experience in Scotland and the U. S. S. R. suggests a relatively low potential for pneumoconiosis for shale dusts in those areas. Four workers have been described as developing pneumoconiosis after work histories of 32 to 53 years of underground oil shale work in Scotland.[19] The authors are unaware of any available dust exposure data for the Scottish oil shale mines.

Pneumoconiosis has not been noted by chest x-ray in Estonian oil shale workers with long exposure histories. Autopsy of workers with 15 or more years of oil shale dust exposure did show them to have moderate fibrosis in the lung and bronchopulmonary lymph nodes.[20] Average dust levels in mines in the U. S. S. R. are reported to range from 6.5 mg/m^3 in drilling for roof bracing to 12.1 mg/m^3 in horizontal blasthole drilling, and even as high an average as 52.7 mg/m^3 in drilling vertical blastholes into the roof. The U. S. S. R. occupational standard for oil shale dust is 4.0 mg/m^3.[21] The quartz content of the airborne dust in Estonian oil shale mines is reported to average 3 per cent. The organic content of the Estonian oil shale is higher than shale from the Green River Formation, averaging some 41 per cent.[20]

Table 1 (extracted from references 3-7 and 9) summarizes results of dust sampling in experimental U. S. underground oil shale mines. These results include data for total dust, respirable dust, and quartz content of the dusts. The samples reported were taken over several years in three oil shale mines with varying levels of mining activity, dust controls, ventilation, moisture, and other factors.

Because total and respirable dust samples were not generally taken at the same time or locations, one cannot directly compare total and respirable dust concentrations to estimate particle size. Cascade impactor samples collected indicate median particle sizes (aerodynamic diameter) in the range of 2 to 3 µm in general mine air samples and some 10 µm near a scaling operation.[2,4-6] The particle size data indicate that the median particle size is relatively small, with some 50-60 per cent considered respirable by criteria of the American Conference of Governmental Industrial Hygienists (ACGIH) in general mine air samples and some 20 per cent considered respirable near the scaling operation sampled.[2,22]

Quartz content of the airborne dust in experimental oil shale mines has been reported to range from 0 to 14.4 per cent.[2,4-6,8] Table 1 also summarizes these results by operation. The overall arithmetic mean for the 59 samples reported is 3.9 per cent. Where x-ray diffraction was utilized for free silica analysis of samples collected by Los Alamos, the results indicate that quartz is probably the only form of crystalline silica of concern; no cristobalite or tridymite were detected.

The ACGIH Threshold Limit Value (TLV) for dusts containing quartz varies with quartz content. Assuming 5 per cent quartz content, the TLV for total dust is 2.8 mg/m^3 and 1.4 mg/m^3 for respirable dust. Corresponding values for dust containing 14 per cent quartz are 1.8 mg/m^3 for total dust and 0.6 mg/m^3 for respirable dust.[23] Dust concentrations reported in Table 1 indicate that dust controls must be emphasized in commercial oil shale mines to prevent miners from being overexposed to dusts containing quartz.

Even at the highest dust concentration reported for experimental oil shale mines (31.9 mg/m^3, ref. 4), trace elements such as arsenic, cadmium, lead, mercury, and nickel should be well below applicable TLV's based upon the reported concentrations of the elements in oil shale. Trace elements in MIS retorting are discussed further later in this paper.

Exposure to Diesel Exhaust. Diesel exhaust contains particles of a high organic content, as well as nitric oxide, nitrogen dioxide, carbon monoxide, carbon dioxide, sulfur dioxide, and organic gases and vapors including aldehydes and polynuclear aromatic hydrocarbons (PAH). Whether diesel equipment in underground mines constitute a health hazard remains a subject of controversy. Little data is available on levels of air contaminants of concern with diesel exhaust in oil shale mines.

The Bureau of Mines has performed ashing of respirable dust samples from an experimental underground oil shale mine which indicate that the organic (non-mineral) fraction of mine samples averaged some 85 per cent, while samples collected near an oil shale crusher of the same facility averaged only some 40 per cent. Scanning electron microscopy also showed qualitatively that the majority of particles in mine air by number were non-mineral.[2]

Los Alamos performed cyclohexane extractions of filter samples collected in an underground oil shale mine and near an oil shale crusher located outside the mine, as well as of finely-ground oil shale in bulk. Extracts from the filters and bulk oil shale were analyzed for 21 polynuclear hydrocarbons and polynuclear heterocyclic nitrogen compounds. The results indicate approximately a two-fold increase in both the total material extracted and the sum of the quantity of the 21 PAH in the mine air sample versus the crusher and bulk shale samples.[4]

The results from these studies suggest that particles originating with diesel exhaust may constitute a large portion of the mine dusts. To date, no toxicological studies have been conducted to examine whether the combination of diesel exhaust particles and oil shale dust may result in potential health hazards to oil shale miners.

Limited sampling has been conducted in experimental oil shale mines on gases and vapors of concern with diesel exhaust.[3-5,7,9] Sampling was conducted at one or more mines for nitrogen dioxide, nitric oxide, carbon monoxide, carbon dioxide, ammonia, sulfur dioxide, formaldehyde, and PAH. The majority of these samples were collected in conjunction with the burn of MIS retorts and were not collected in proximity to operating diesel equipment. None of the available data indicate levels of any of these air contaminants in excess of applicable TLV's; most results are non-detectable or far below TLV's.

Extensive data have been collected by MSHA at a number of other metal and non-metal mines in which diesel equipment are utilized.[24] These include data on carbon monoxide, nitrogen oxides, sulfur dioxide, ammonia, aldehydes, and carbon dioxide. Very few of the mines had levels of any of these compounds which exceed applicable TLV's. The results indicate that ventilation rates utilized in commercial mines appear to be adequate to maintain concentrations of gases associated with diesel exhaust below applicable TLV's.

The scale of commercial oil shale mines may affect exposure to diesel exhaust contaminants. Commercial oil shale mines are expected to utilize larger diesel equipment than is currently used in underground mining. The very large rooms represent much larger volumes for dilution of diesel exhaust or other air contaminants, but the efficacy of ventilation in such very large rooms is not proven. Air velocities may be expected to be lower due to the large cross-sectional area of drifts.

Exposures Due to Blasting. The danger of toxic gases produced by the detonation of explosives in underground mines has been recognized since the early 1900's.[25] Gases of primary concern with the use of ANFO for blasting are carbon monoxide, nitric oxide, nitrogen dioxide, and carbon dioxide. Dust and organic gases and vapors will also be produced.

Blasting at experimental oil shale mines appears to have generally been conducted at the end of a shift, with the return of miners the following day or after a weekend. Commercial oil shale mines are expected to involve mining on a 24-hr/day, 7-day/week basis. Blasting will be conducted between shifts, but miners will return shortly after blasting.

Only very limited data are available on levels of dusts, gases and vapors created in oil shale mines by blasting.[4,9,26] These data indicate that levels of dusts, carbon monoxide, and nitrogen dioxide may exceed TLV's after blasting. Ventilation will be required in commercial mines prior to the return of personnel.

Gases Released From Mine Water and Oil Shale. Deep oil shale mines located in the center of the Piceance Basin of Colorado have been found to be "gassy."[27,28] Gassy conditions are also expected within underground mines in Utah. Mines along the outcrop on the southern edge of the Piceance basin are not expected to experience such problems; none of the experimental mines along the outcrop have been gassy.[11] Gases of primary concern in gassy mines are methane and hydrogen sulfide. Methane is a simple asphyxiant and should not be a health hazard at levels that are safe from the standpoint of fire prevention (i.e., less than 1.0 per cent methane in air).

Hydrogen sulfide appears to be associated with mine water. Hydrogen sulfide has been measured to range from 0.5 to 10 ppm near the mine-water sump of an experimental oil shale mine, even with a high rate of ventilation in the area.[5] The TLV for hydrogen sulfide is 10 ppm.[23]

The emanation of radon gas from surrounding rock is a concern in several types of underground mines. Persons within both the oil shale industry and MSHA have stated to one of the authors that radon is not a problem in underground oil shale mines. The authors are not aware of published data from radon daughter measurements in oil shale mines. Radon daughter measurements have apparently been conducted by MSHA in at least one experimental oil shale mine, with results of these measurements stated to be <0.1 working level. The sampling results are thought to be in MSHA archives at Denver, but were not available to the authors at the time of preparation of this report.

<u>Noise and Vibration.</u> Noise associated with mining and ventilation equipment is a problem throughout the mining

industry.[29] Los Alamos has conducted a noise survey in an experimental underground oil shale mine during the burn of an MIS retort. Noise levels exceeded 90 dBA near booster fans, and in both mine water and product pump areas.[30] Although not measured, extremely high noise levels were also observed in the same mine previously during operation of diesel load-haul-dump vehicles, pneumatic drilling for roof bolts, and in operation of the mechanical rock breaker.

The Bureau of Mines sponsored a 1974 and 1975 study of noise exposures associated with the operation of diesel-powered underground mining equipment.[29] Of 19 pieces of mining equipment evaluated, only 2 had noise levels which were less than 90 dBA. One of those two was also greater than 90 dBA when tested underground. Equipment tested in that study which are expected to be used in commercial oil shale mines (and noise levels measured at the position of the operator of the equipment in that study) include front-end loaders (98 dBA underground), jumbo drills (92 dBA aboveground), ore trucks (103 dBA underground), and roof-bolting machines (96 dBA).

No studies have been conducted in U. S. oil shale mines concerning effects of vibration of mining equipment on miners. Reports of studies conducted at oil shale mines in the U. S. S. R. indicate that vibration disease was diagnosed in almost one-third of the drillers examined. Signs of vibration disease in drillers using manual electric drills for almost the entire workday were reported to appear after 7-8 years of exposure on average. Workers exposed to vibration for 1/5-1/3 of the workday developed vibration disease after an average of 13 years of service.[31]

The scale of mining proposed for U. S. oil shale mines will likely mean reduced exposure to vibration as the operators of jumbo drills will be relatively isolated from local vibration of the drill rods. Manual pneumatic drills have been observed, however, in use in rock bolting in an experimental oil shale mine. Rotary-percussion drills have also been used for roof bolting in another experimental oil shale mine.[10]

Environmental Conditions. Mining may take place under poor environmental conditions of insufficient lighting as well as cold, dampness, and high humidity. Fixed lighting will be used in very few areas, although lights on diesel equipment will supplement that from miners' lamps. Large quantities of underground water were encountered at a deep underground mine in the center of the Piceance basin, as well as in sinking a deep shaft.[27,28] Mines along the outcrop may also encounter some underground water, and it is expected that water will also be used for dust control at all oil shale mines. Large volumes of ventilation air will be used in commercial oil shale mines. For example, it has been reported that more than 113,400 m^3/min (4 million cfm) of ventilation air will be required at the Colony commercial oil shale mine.[11] Air used in ventilation will be very cold in the winter months. It is not likely that tempering of the air will be feasible due to the large volumes of air that will be used. The result is that miners in commercial oil shale mines may be exposed to conditions of wet and cold, with high humidity.

Similar conditions have been described in oil shale mines in the U. S. S. R. These conditions have been attributed to causing colds. Chronic rhinitis, tonsillitis, and bronchitis are also reported to be of increased incidence in the Estonian oil shale mines. In addition to the climatic factors, shale dust is stated to be one of the causes of these diseases.[31]

Modified in situ retorting. The MIS retorting process may present unique occupational exposures relative to those commonly encountered in underground mining. Miners preparing retorts underground will be in proximity to previously-prepared retorts that are burning or cooling down. Some possibility exists for the escape of retort offgases into the mine (through fractures in the oil shale) from burning or newly-abandoned retorts, even though gas-tight bulkheads are constructed and retorts are normally operated at negative pressure relative to the surrounding mine. Retort offgases contain high concentrations of carbon monoxide, hydrogen sulfide, ammonia, and hundreds of organic compounds.

Shale oil and water produced in retorting will flow to the bottom of the MIS retort and on to sumps located within the mine.

From the sumps, the retort products will be pumped to the ground surface for separation and processing. Workers in the area of sumps and pumping facilities may be exposed to vapors from the retort products. Skin contact with the retort products may also occur in maintenance and repair of equipment.

The health significance of the very complex combination of organic vapors from shale oil and retort offgases is not known at this time. The components of the vapors and offgases have not been well characterized, and no inhalation toxicology studies have yet been conducted on these products. The presence of aromatic and polynuclear aromatic hydrocarbons raises concerns of carcinogenicity. The hazards of repeated and prolonged skin contact with shale oil are well known. The experience of the early Scottish industry with skin cancers has been widely reported, as has the high incidence of skin cancers in the "mule spinners" of the cotton industry where the shale oil was used for lubrication.[32] Shale oils from several retorting processes being developed in the U. S. have also been found to cause skin cancers in animals.[32,33]

Several short-term industrial hygiene studies have been conducted in experimental oil shale mines in conjunction with the burn of experimental or pilot-scale MIS retorts.[5-7,9] Some mining activity was also going on. Low or non-detectable levels of most air contaminants sampled were observed in each of these studies. Table 2 contains a summary of the results from a study by Los

Alamos.[5] There was an apparent increase in the concentration of the sum of the seven PAH measured during the burn relative to the concentration measured prior to the burn. The levels of most gases and vapors were not detectable with the sampling and analytical methods employed. Hydrogen sulfide (H_2S) was observed in association with the mine water, with highest H_2S concentrations measured at the mine-water sump. Higher levels of H_2S were observed prior to initiation of the burn of the retort than during the retort burn.

Studies by NIOSH and MSHA in two experimental MIS oil shale mines have included analyses of trace elements in airborne dust.[7,9] Elements analyzed included arsenic, cadmium, lead, nickel, cobalt, chromium, beryllium, and vanadium. Mercury vapor sampling was also conducted by MSHA.[7] Where detectable, the elements were reported at very low levels relative to the TLV's.

CONTROLS FOR POTENTIAL HEALTH HAZARDS

Controls for potential health hazards are expected to be similar to those currently in use in underground mines. Engineering controls are preferred, but personal protective equipment will likely be necessary in some situations. Water will be used to control dust in drilling. Water sprays will reduce dust from scaling, mucking, loading, and haulage roads. Dust from operations such as crushing can be collected and controlled by a variety of available equipment. Ventilation will be the primary means of reducing exposures from diesel exhaust and blasting, as well as gases such as hydrogen sulfide and methane. Diesel mining equipment may also be equipped with devices such as scrubbers and catalytic converters to reduce exhaust emissions.

The very large scale of diesel equipment planned for underground oil shale mining will also permit the enclosure of operators with air filtration for dust control, insulation and damping for noise control, and air conditioning or heating for control of adverse environmental conditions. Where miners are required to work outside equipment enclosures in dusty areas, respirators may be required. It appears unlikely that engineering controls will be adequate to reduce noise levels below 90 dBA with most types of equipment in the near future, and personal protection will likely be required to protect miners' hearing.

SUMMARY AND CONCLUSIONS

Commercial oil shale mining will be conducted on a very large scale. Conventional mining techniques of drilling, blasting, mucking, loading, scaling, and roof bolting will be employed. Room-and-pillar mining will be utilized in most mines, but mining in support of MIS retorting may also be conducted. Potential health hazards to miners may include exposure to oil shale dusts, diesel exhaust, blasting products, gases released from the oil shale or mine water, noise and vibration, and poor environmental conditions. Mining in support of MIS retorting may in addition include potential exposure to oil shale retort offgases and retort liquid products. Based upon the very limited industrial hygiene surveys and sampling in experimental oil shale mines, it does not appear that oil shale mining will result in special or unique health hazards. Further animal toxicity testing data could result in reassessment if findings are unusual. Sufficient information is available to indicate that controls for dust will be required in most mining activities, ventilation will be necessary to carry away gases and vapors from blasting and diesel equipment, and a combination of engineering controls and personal protection will likely be required for control of noise.

RECOMMENDATIONS FOR FUTURE WORK

As noted above, the industrial hygiene studies which have been conducted in experimental oil shale mines have been limited in duration, and have not adequately examined all mining operations. Sampling for gases and vapors has primarily been conducted in conjunction with MIS retorting. Studies on MIS retorting have not addressed the situation of a number of commercial-scale retorts operating at the same time or abnormal situations such as retorts operating under positive pressure. Comprehensive, long-term industrial hygiene studies in operating oil shale mines are needed to truly assess the potential health hazards and controls in commercial mines.

Additional long-term toxicological testing of low levels of oil shale dusts and oil shale dust in combination with retort offgases is needed to further evaluate potential health hazards with these materials. Although industrial hygiene and epidemiologic studies are being conducted in coal, metal, and nonmetallic mines having operating diesel equipment, nothing is known of potential health hazards of a combination of diesel exhaust and oil shale dusts. Long-term toxicological studies are also needed to evaluate this problem.

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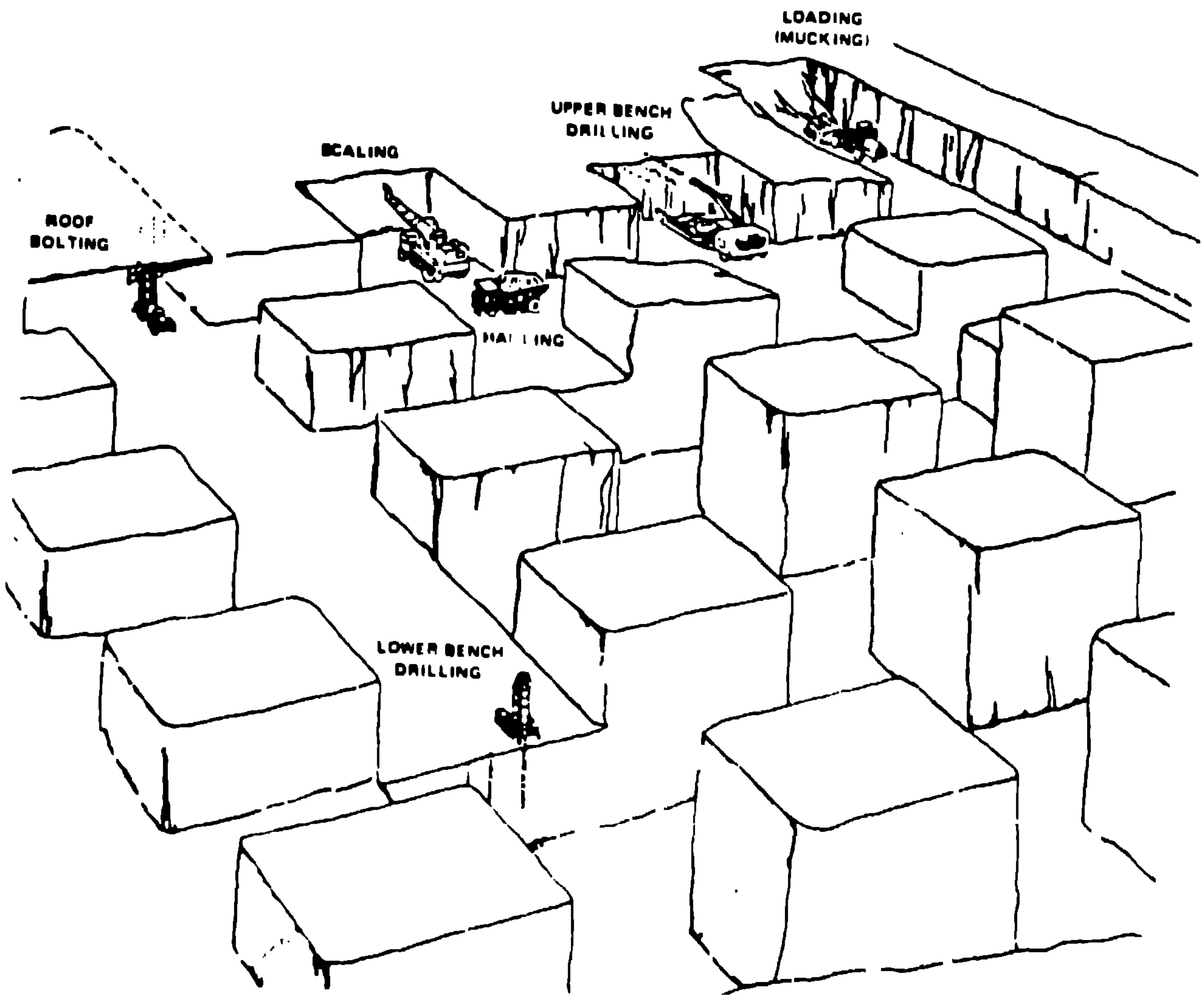

FIGURE 1. ROOM-AND-PILLAR MINING OF OIL SHALE.
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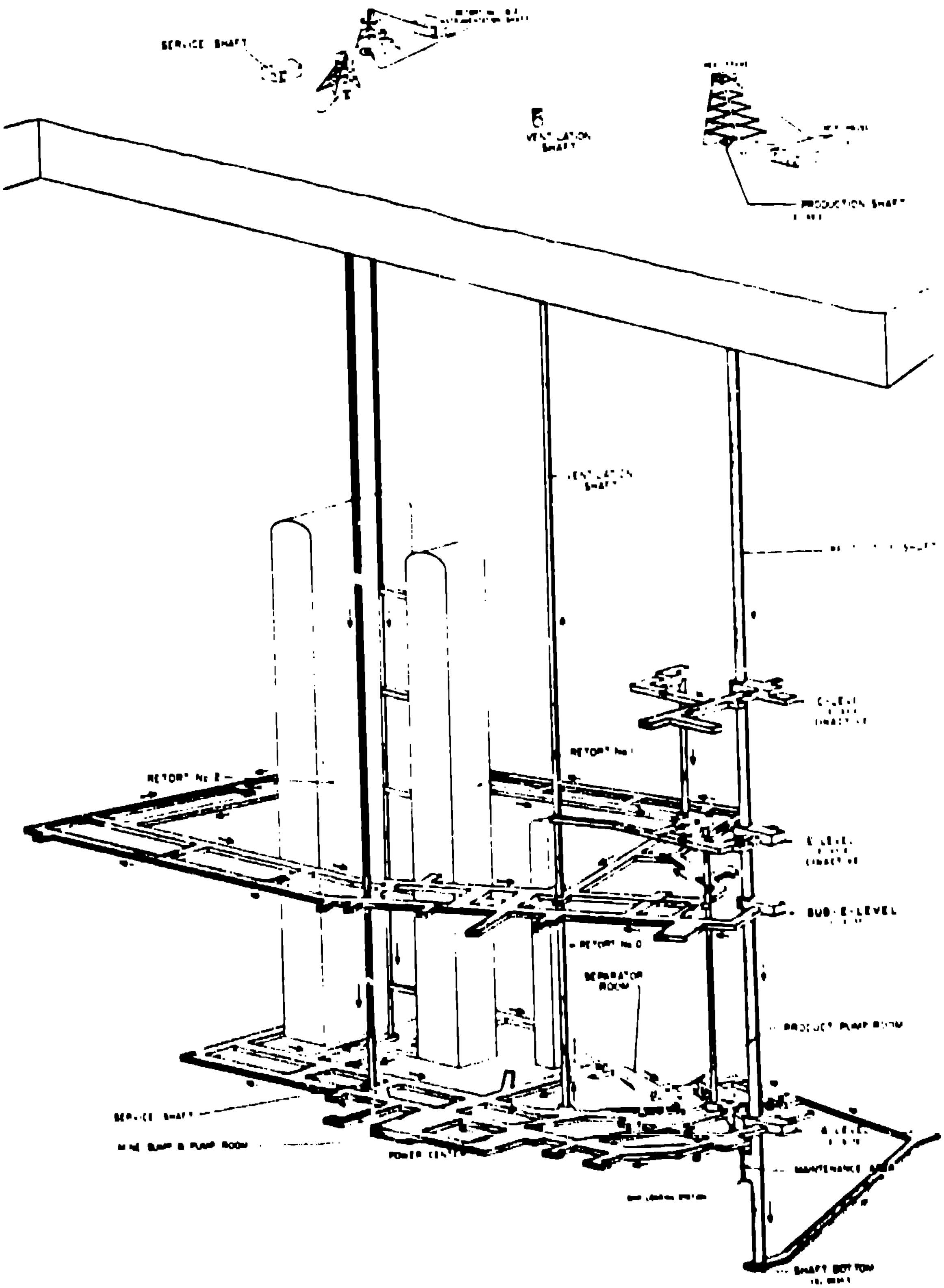

FIGURE 2. ISOMETRIC VIEW OF THE RIO BLANCO OIL SHALE COMPANY'S EXPERIMENTAL MODIFIED IN SITU OIL SHALE MINE. (From Reference 5).

FIGURE 3. INSIDE AN EXPERIMENTAL ROOM-AND-PILLAR OIL SHALE MINE.

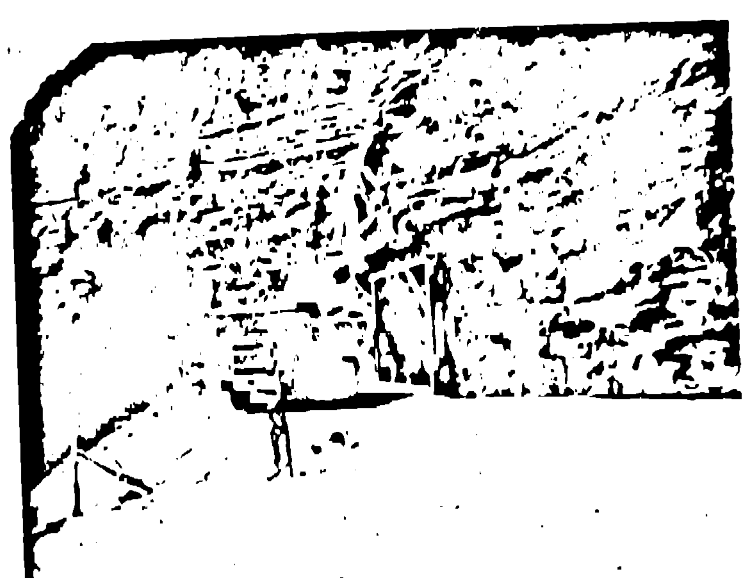

FIGURE 4. HAULAGE TRUCK LEAVING ADIT AT EXPERIMENTAL OIL SHALE MINE.

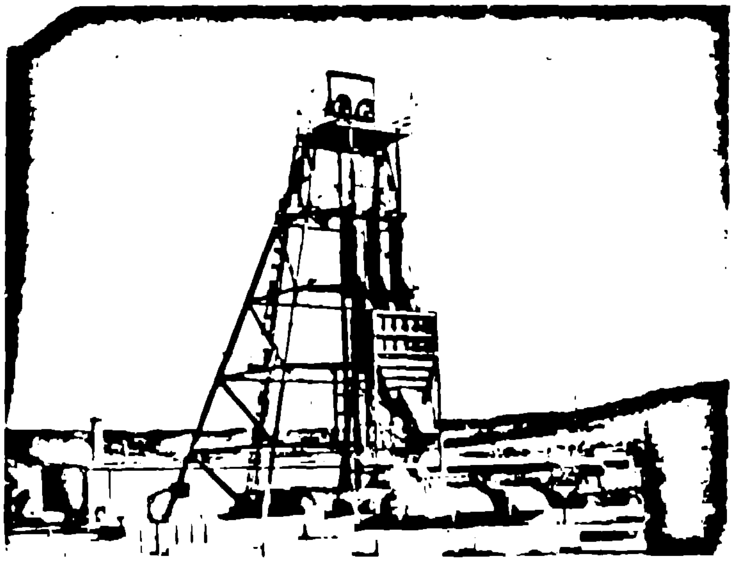

FIGURE 5. HEADFRAME FOR HOIST ON VERTICAL SHAFT AT EXPERIMENTAL OIL SHALE MINE.

FIGURE 6. DRILLING BLASTHOLES IN WALL AT EXPERIMENTAL OIL SHALE MINE.

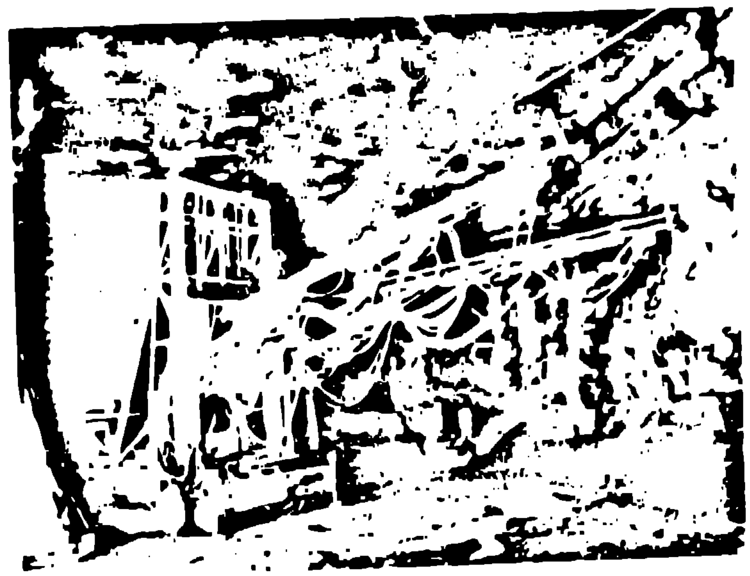

FIGURE 7. CLOSE-UP OF ROTARY JUMBO FOR DRILLING BLASTHOLES.

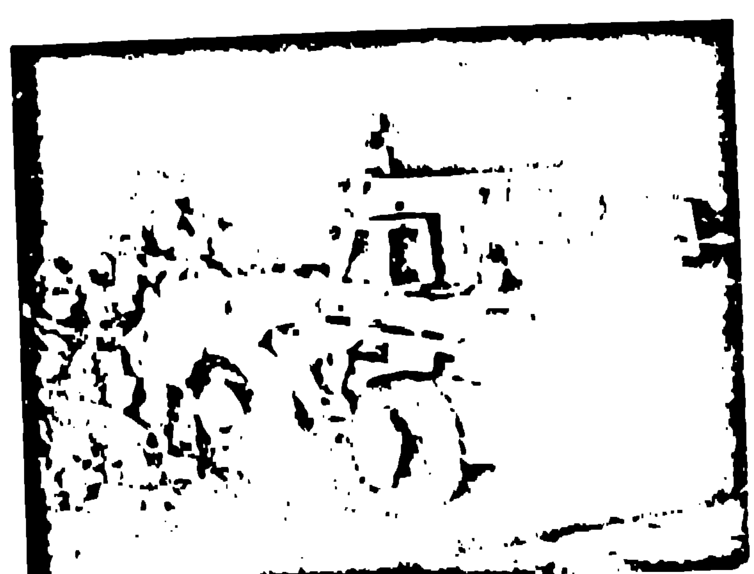

FIGURE 8. MUCKING OPERATION AT AN EXPERIMENTAL OIL SHALE MINE.

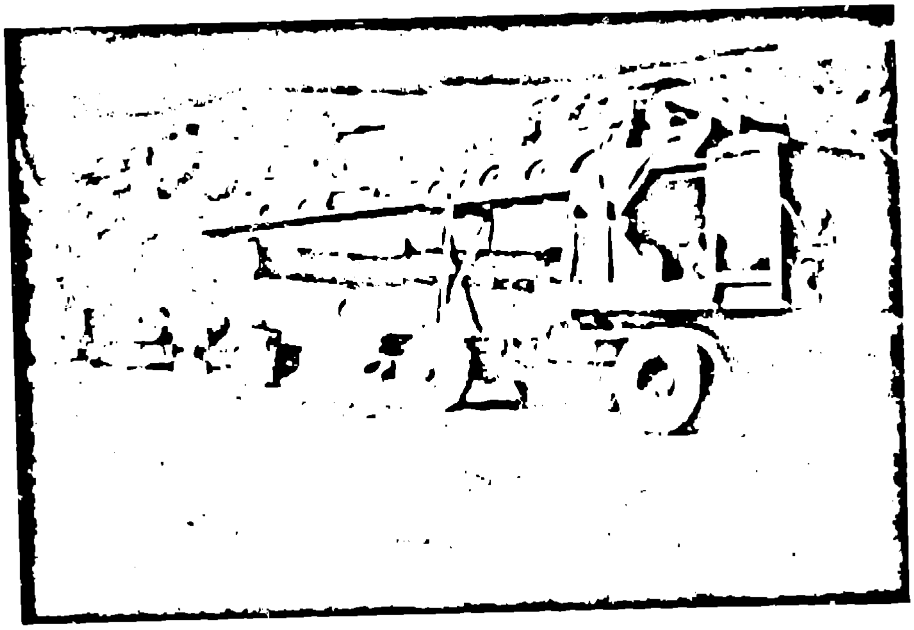

FIGURE 9. EQUIPMENT USED FOR SCALING OPERATION AT EXPERIMENTAL OIL SHALE MINE.

TABLE 1

DUST SAMPLING IN OIL SHALE MINES
(EXTRACTED FROM REFERENCES [illegible], 4, 5, 6, 7, and 9)

OPERATION	TOTAL DUST (mg/m^3) NO.	MAX.	MEAN	RESPIRABLE DUST (mg/m^3) NO.	MAX.	MEAN	QUARTZ CONTENT (%) NO.	MAX.	MEAN
Blasthole Drilling	7	31.9	14.7	5	14.6	6.4	2	5.4	4.9
Blasting	--	----	----	--	----	----	3	14.3	14.0
Mucking, Loading	4	14.1	8.2	14	3.0	1.0	12	14.4	4.6
Scaling	--	----	----	4	2.7	1.7	4	6.7	2.4
Roof Bolting	1	----	12.6	3	0.8	0.6	3	2.3	1.8
General Mine/ Unspecified	52	14.6	1.2	45	2.9	0.6	35	9.9	3.1

Table 2

AIR SAMPLES FROM EXPERIMENTAL OIL SHALE MINE DURING BURN OF MIS RETORT
(From Reference 5)

CONTAMINANT	NO. OF SAMPLES	THRESHOLD LIMIT VALUE	RESULTS
Dusts			
Total Dust	45	3.8 mg/m^3 [a]	0.27–2.91 mg/m^3
Respirable Dust	33	1.4 mg/m^3 [a]	0.09–1.20 mg/m^3
Per Cent Dust	20	---	<1.5–4.4 per cent
PAH[b]	6	---	37–689 mg/m^3
Gases and Vapors			
Carbon Monoxide	28	50 ppm	<5 ppm
Hydrogen Sulfide	26	10 ppm	<0.5–10 ppm
Nitrogen Dioxide	14	5 ppm	<0.2 ppm
Sulfur Dioxide	18	2 ppm	<0.2–1.5 ppm
Arsine	12	0.05 ppm	<0.05 ppm
Formaldehyde	15	2 ppm	<0.3 ppm
Total Amines	18	10 ppm[c]	<0.4–1.3 ppm
Benzene	40	10 ppm	<0.02 ppm
Toluene	40	100 ppm	<0.02 ppm
Phenol	40	5 ppm	<0.002 ppm
Carbon Disulfide	1	10 ppm	<50 ppm

[a] TLV assuming 5% quartz.

[b] Polynuclear Aramotic Hydrocarbons (PAH) – Sum of anthracene, benzo(a)pyrene, chrysene, fluorene, phenanthrene, and pyrene.

[c] TLV for methyl amine.